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PHYSICS.—*A note on the standard scale of temperatures between 200° and 1100°.* L. H. ADAMS and J. JOHNSTON, Geophysical Laboratory.

The original measurements recorded in this note were made over a year ago in connection with another investigation; they determine the freezing points of the four metals, tin, bismuth, cadmium and lead, in terms of the boiling points of naphthalene and benzophenone. The agreement of these results with the best resistance thermometer measurements of the same fixed points shows that the thermocouple is not inferior to the resistance thermometer as an accurate temperature measuring device within the temperature range in question. In addition, it is shown that the most thorough and most extensive series of resistance thermometer measurements—those of Waidner and Burgess, made at the Bureau of Standards—are also in remarkable agreement over the whole range of temperature (up to 1100°) with the gas thermometer measurements of Day and Sosman, when they are expressed in the same scale. At the same time, this comparison shows that, if we consider all of the points,[1] excepting sulphur, to be fixed by the gas thermometer work, and on this basis set up an interpolation formula and calculate therefrom the boiling point of sulphur, the resistance thermometer measurements lead to a value (444°.56) identical with the gas thermometer determinations.

The calibration of the thermoelements has already been described[2] but the account there given must be amplified by the following additions and corrections, which are rendered necessary by the slight changes

[1] Namely, the boiling points of naphthalene and benzophenone, and the freezing points of tin, cadmium, zinc, antimony, silver and copper.

[2] Am. J. Sci. 31: 501–17. 1911.

in the temperature scale resulting from the new and more accurate gas thermometer determinations at temperatures up to 500.°

Too much reliance can not be placed on the readings of copper-constantan thermoelements at the zinc-point (419°.4), for some diminution of electromotive force sets in, not serious, but sufficient to preclude the most accurate measurement; for this reason we have ceased to make use of the zinc point as a calibration temperature.

The calibration temperatures, expressed in the corrected scale, together with the corresponding values of electromotive force of the standard element, are given in Table I.

TABLE I

CALIBRATION TEMPERATURES

	e IN MICROVOLTS		DIFFERENCE	
	Observed	Calculated	In microvolts	In degrees
0	0	0	0.0	0.0
25.00	979	980.0	−1.0	−0.025
50.00	2012	2012.7	+0.7	+0.016
75.00	3096	3095.8	+0.2	+0.005
100.00	4227	4226.1	+0.9	+0.019
217.95	10119	10119.3	−0.3	−0.005
306.1*	15007	15007.0	0.0	0.0

* The benzophenone used was from Merck, which melts at (46°.9) 0°.3 lower, and boils 0°.2 higher, than that obtained from Kahlbaum (Waidner and Burgess, Bull. Bur. Standards, 7: 3–11; 1910). The f. p. of our Merck benzophenone was also 46°.9; consequently we have added 0°.12 to the accepted b. p. (305°.9) of Kahlbaum benzophenone.

To reproduce the above data, a quadratic equation is insufficient, except over a very short range, and so is the cubic equation[3] of the form $t = A\,e + B\,e^2 + C\,e^3$; but they can, as we found, be fitted very closely by the inverse form of function, $e = A\,t + B\,t^2 + C\,t^3$. Accordingly, on this basis a least square solution for all the points in Table I was made; this resulted in the equation

$$e = 38.105\ t + 0.04442\ t^2 - 0.00002856\ t^3,$$

from which the figures in the third column of Table I have been computed. The agreement is excellent; it can not, however, be used as a valid argument in favor of the accuracy of either the temperature scale or of the measurements, as anyone can readily convince himself by working with a number of similar cubics. By computation from this equation, a table giving t in terms of e was constructed.[4]

[3] This was tried because its use would have saved so much trouble in calculating the most convenient form of table—that giving t for round values of e.

[4] This table is presented in full in the more complete paper in Am. Jl. Sci.

The identity of the readings of the thermoelement and the resistance thermometer at boiling points and melting points. The initial series of measurements gave differences between the freezing point of tin and the naphthalene point on the one hand and between the freezing point of cadmium and the benzophenone point on the other,—using our own apparatus and materials—which were 0°.2 higher than the corresponding differences obtained by Waidner and Burgess at the Bureau of Standards. This lack of agreement disappeared[5] when we determined all the points on the identical samples of material used by Waidner and Burgess, which they were kind enough to lend us.

In Table II we present our results. In the boiling point experiments, three forms of apparatus were used; one (B in the table) of glass[6]—with an aluminium shield for the thermo-couple; the second (A) of brass with an inner tube of thin copper to prevent radiation; and the third (S) similar to the second, but of slightly different dimensions. Four different elements were used, one (E) of platinum—platin-rhodium, the other three (C_1, C_2, C_3) of copper-constantan (No. 30 wire = 0.25 mm. diam.)

The electromotive forces at the freezing points were reduced to degrees with the aid of the table; the boiling points were reduced to normal pressure by means of this table and the formulae: for naphthalene, $T_{760} = T - 0.058\ (p - 760)$; for benzophenone, $T_{760} = T - 0.063\ (p - 760)$. The freezing points have been given to hundredths of a degree, as relative values for purposes of comparison only; their absolute accuracy is of the order of 0°.1.

This table shows that the boiling points are independent of the apparatus and sample of material employed, and that the freezing points can be reproduced satisfactorily on different days and with varying set-up; e.g., the results are independent of the size and kind of tube—glass or porcelain—used to protect the thermo-couple from the metal, and of the size of the charge.

In order to make the data of Waidner and Burgess more truly comparable with our own, we have reduced them to the scale of temperature on which our own values are based (cf. *postea*, Table IV), and present these reduced values in the last column of Table II. The differences between the values for the adjacent freezing and boiling points are compared in Table III with the analogous differences derived from our thermoelectric measurements.

The differences, therefore, as determined by us with platin-rhodium and copper-constantan thermoelements in various forms

[5] The divergence was due to slight impurities in our tin and to the fact that the benzophenone used was from Merck (cf. footnote, to Table I).

[6] Lent to us by the Bureau of Standards.

of apparatus on the one hand, and with resistance thermometers at the Bureau of Standards or at the Reichsanstalt on the other, agree very satisfactorily. This proves conclusively, that there is no systematic deviation whatever, within the range of these measurements, between the readings of these two kinds of thermometers—either at boiling points or at melting or freezing points—when both are calibrated with reference to the same temperature scale. This position is confirmed by a direct comparison of the series of measurements by Waidner and Burgess of the resistances of platinum thermometers with the recent gas thermometer measurements of Day and Sosman,[7] transferred by means of thermoelements to the same fixed points.

So far we have dealt with temperatures less than about 330°; but the comparison just referred to enables us to extend the same conclusion to the copper point (1083°), beyond which the readings of the usual form of resistance thermometer are no longer trustworthy.

TABLE II

BOILING POINTS OF NAPHTHALENE AND BENZOPHENONE

SUBSTANCE	SOURCE	APPARATUS	THERMOCOUPLE*	FROM THERMOELECTRIC MEASUREMENTS (ADAMS & JOHNSTON)		FROM RESISTANCE THERMOMETER MEASUREMENTS (WAIDNER & BURGESS)	
				Microvolts	Degrees	As given by them†	When reduced to our scale‡
Naphthlene	Merck	A	E	1585.7¶			
	Kahlbaum	B	E	1585.3			
		B	C_1	10119.0	(217.95)	218.0	217.97
		A	C_3	10119.0¶			
	Merck	A	C_3	10118.5			
		A	C_2	10120.0			
Benzophenone	Merck (b)	A	E	2366.2¶			
	Merck (a)	A	E	2366.3			
		S	C_1	15008.0	(306.1)	306.2	306.11
		A	C_1	15007.0¶			
		S	C_2	15010.0			
		A	C_3	15004.0			
	Merck (b)	A	C	15005.5¶			

[7] Am. J. Sci., **29**: 93–161. 1910; Carnegie Institution of Washington, Publication No. 157. 1911. cf. also J. Wash. Acad. Sci. **2**: 167–76. 1912.

TABLE II—Continued

FREEZING POINTS OF METALS

METAL	SOURCE	QUANTITY OF METAL	THERMOCOUPLE*	FROM THERMOELECTRIC MEASUREMENTS (ADAMS & JOHNSTON)		FROM RESISTANCE THERMOMETER MEASUREMENTS (WAIDNER & BURGESS)	
				Microvolts	Degrees	As given by them‡	When reduced to our scale§
		grams					
		1500	C_1	10861.0	231.75		
		1500	C_1	10859.0	231.71		
		1500	C_3	10863.0	231.79		
		200	C_3	10856.0	231.67		
Sn	Kahlbaum					231.92	231.88
		200	E	1706.0	231.9		
		200	E	1706.0#	231.9		
		1500	E	1706.0	231.9		
		1500	E	1706.0	231.9		
			C_1	13020.0	270.99		
Bi	J. T. Baker		C_1	13015.0	270.90		
			C_1	15860.0	320.92		
			C_3	15858.0	320.92		
Cd	Kahlbaum					321.01	320.92
			E	2502.5	320.9		
			E	2560.5	327.2		
						327.27	327.19
Pb	Kahlbaum		C_1	16227.0	327.28		
			C_3	16226.0	327.30		

* Couple E is of Pt—PtRh; C_1, C_2, C_3 are of copper-constantan.

† Bull. Bur. Standards, **7**: 3–11. 1910. (Reprint No. 143.)

‡ Ibid. **6**: 150–230. 1910. (Reprint No. 124).

¶ The values given in the last column have been reduced from those in the column to the left by means of the differences between the scales as determined in a way to be described later (p. 280); i.e., these values are on the basis that the b. p. of sulfur is 444°.56.

§ Mean of two or more determinations often separated by a month or so in time. The maximum deviation from the mean in any of these cases was 0°.03.

Melting point.

Comparison of the series of resistance thermometer measurements (Waidner and Burgess) *with gas thermometer determinations* (Day and Sosman) *at the same fixed points.* For a fair comparison it is essential that the results be expressed in the same scale of temperatures; for this we have adopted the thermodynamic scale. We have accordingly applied the appropriate corrections, taking

a mean of the correction numbers collated by Buckingham,[8] to the results of Day and Sosman, which were determined on the constant volume scale. The uncertainty of the gas thermometer determinations is indeed comparable with the magnitude of these corrections; nevertheless we have, for the sake of definiteness, considered it advisable to apply them.

TABLE III

COMPARISON OF TEMPERATURE INTERVALS AS MEASURED BY THERMOELEMENTS AND BY THE RESISTANCE THERMOMETER

INTERVAL	TEMPERATURE DIFFERENCE AS DERIVED FROM MEASUREMENTS WITH				
	Thermoelements			Resistance Thermometer	
	E*	C_1	C_3	Waidner & Burgess	Holborn & Henning
Sn – naphthalene	13.9	13.78	13.78	13.91	13.87
Cd – benzophenone, Merck	14.8	14.82	14.82	14.81	
Cd – benzophenone, Kahlbaum	15.0	15.02	15.02	15.01	15.03
Pb – Cd	6.3	6.36	6.38	6.43	

* When reading only to 1 microvolt, as we were, it is illusory to give the readings of the platin-rhodium element closer than the nearest tenth of a degree.

The results as given by Waidner and Burgess[9] were derived by means of the Callendar formula,[10] the third calibration temperature being the sulfur boiling point taken as 444°.70. In order to refer these values to the comparison scale, it seemed simplest to substitute in the Callendar equation the simultaneous values of the thermodynamic temperature (t) and the platinum temperatures of a single resistance thermometer[11]

[8] Bull. Bur. Standards, 3: 288–9. 1907; (reprint No. 57).

[9] Ibid, 6: 150–223. 1910; (reprint No. 124); 7: 1–11. 1910; (reprint No. 143).

[10] The Callendar formula is $t - p = \delta\left(\frac{t}{100} - 1\right)\frac{t}{100}$, where t is the true temperature, and pt (the so-called platinum temperature) is defined by the relation

$$pt = \frac{100\,(R_t - R_o)}{R_{100} - R_o}$$

(R_t is the resistance at $t°$). δ is a deviation constant derived by means of the formula from the third calibration temperature (usually the sulfur boiling point); for pure platinum δ, as thus obtained, is close to 1.50. The formula is essentially a simple quadratic relation of the form

$$R_t = R_o + at - bt^2.$$

[11] No. 1787C; this instrument was used over the widest range and appears to be the most satisfactory of those used at the Bureau of Standards.

as measured by Waidner and Burgess, and to compute in this way the corresponding values of δ'. These values vary irregularly at the lower temperatures, as might be expected, since the influence of variation of δ is small when t is small; but at the higher temperatures they show a distinct upward trend, and can be represented very fairly by the relation $\delta' = 1.489 + 0.000015\ t$. These values of δ' were combined with the respective platinum temperatures to give new values of the temperature, which were then subtracted from the temperatures as given by Waidner and Burgess;[12] thus giving the differences between the two scales at these points. These differences were applied to the average values

TABLE IV

COMPARISON OF THE "CORRECTED" TEMPERATURES (MEASURED BY THE RESISTANCE THERMOMETER) WITH DETERMINATIONS BY THE GAS THERMOMETER AND WITH THERMOELEMENTS. THERMODYNAMIC SCALE

	TEMPERATURE BASED ON GAS THERMOMETER MEASUREMENTS (D. & S.) I	"CORRECTED" TEMPERATURES FROM RESISTANCE THERMOMETER MEASUREMENTS (W. & B.) II	DIFFERENCES II−I
Nph., b.p.	217.95	217.97	+0.02
Sn., f.p.	231.73*	231.88	+0.15
Bnz., b.p.	305.90†	305.91	+0.01
Cd., f.p.	320.92*	320.92	0.00
Pb., f.p.	327.39*	327.35	−0.04
Zn., f.p.	419.4†	419.24	−0.16
S., b.p.	444.55‡	444.55	0.00
Sb., f.p.	630.0†	630.36	+0.36
Ag., f.p.	960.4†	960.7	+0.3
Cu., f.p.	1083.2†	1082.8	−0.4

* From the thermoelectric measurements of Table III above.

† Temperatures transferred from gas thermometer measurement to fixed point by thermocouples.

‡ Direct gas thermometer determination.

given by Waidner and Burgess, giving the "corrected" average temperatures presented in Table IV, column I. Alongside of this we have tabulated (in column II) the temperatures on the thermodynamic scale as derived from the work of Day and Sosman, and (in column III) the differences between these two sets of measurements.

The differences at the tin and zinc points are no doubt due to the fact that in these two cases the determinations were made on different samples of metal; with these two slight exceptions the agreement is all that

[12] That is, the temperatures as derived from a fixed δ, obtained by calibration at 0°, 100°, and the S.B.P. taken as 444°70.

could be desired. This concordance shows further that if we derive an interpolation formula for the resistance thermometer based on all of the points excepting sulfur, and calculate by means of this formula the boiling temperature of sulfur, we obtain a result identical with the direct gas thermometer determination of this fixed point.

If we recalculate the above temperatures using a fixed value of δ based on the newer determinations of the sulfur point, we obtain results which are practically identical with those of column II (Table IV) except at the silver and copper points, which would on this basis be lower by 0°.6 and 0°.9 respectively. This silver point would still be within the limits of accuracy of the gas thermometer measurements at that point, but the divergence at the copper point (1°.3) is somewhat greater than the probable error.

This raises the question of the range through which the simple, and very convenient, Callendar formula is applicable in accurate work. It does not hold for impure platinum or for palladium;[13] nor does it hold for pure platinum at all temperatures below 0°C. Indeed Travers and Gwyer say: "A standard scale of temperature, based on Callendar's three fixed points, using standard wire, and taking 1.5 for the value of δ, would obviously lead to absurd results at low temperatures; and the converse may be said of our own observations;"[14] and conclude that the Callendar formula cannot be made use of except for interpolation. There is thus ground for believing that the accuracy of the results calculated from the change of resistance of *pure* platinum by means of the simple Callendar formula is to some extent fortuitous. The small variation of δ introduces uncertainties which would appear to be too great for the most accurate work except over the temperature range included between the fixed calibration points (0°–444°.55), and a short region beyond (perhaps to 750°).[15] On the other hand it must be admitted that the cubic term (which expresses the variation of δ with the temperature) is very small—so small that its effect is scarcely greater than the uncertainty in the gas thermometer determinations at the higher temperatures.

[13] Waidner and Burgess, Bu'l. Bureau Standards, **6**: 176, 183. 1910.

[14] Proc. Roy. Soc. London, **74**: 538. 1904–5.

[15] The effect of slight changes of δ on the calculated temperatures may be gauged from the following: that a change of 0°.2 in the boiling point of sulfur changes δ by 1 per cent (and proportionally for other small changes); this in turn affects temperatures of 300° or lower by 0°.1 or less, but affects the antimony point by 0°.5 and the copper point by 1°.6.

In this connection one point remains to be noted—namely the accuracy of the Reichsanstalt scale in the region 1000–1100°. Holborn and Valentiner state in one place[16] that the uncertainty at 1000° amounts to 2 to 3°; in another place,[17] in discussing the reliability of their newer measurements at high temperatures, they state that there is a difference amounting to 5° between the older (1900) and the newer (1906) Reichsanstalt determinations at 1100°, and continue: "The deviation from the mean would still fall within the limits of error of the earlier determinations. We consider it better however to attach greater weight to the former measurements, because the temperature gradient in the gas thermometer bulb was much smaller in the earlier measurements." This may well be, for they give figures[18] which show that in the 1906 determinations at 1124° there were differences of temperature from one point of the bulb to another of as much as 346 microvolts, or about 29°.

Summary. In this note a new calibration curve for copper-constantan thermo-elements, extending from 0° up to 360°, is given, together with a series of independent measurements of the temperature differences between the boiling points of naphthalene (217°.95) and benzophenone (305°.9) on the one hand, and the freezing points of tin, bismuth, cadmium and lead on the other. These measurements lead to the following values of the freezing points: Sn, 231°.8; Bi, 271°.0; Cd, 320°.9; Pb, 327°.3. The concordance of these values with those obtained by other measurements show that the thermoelement is not inferior to the resistance thermometer within this range of temperature (0 to 360°). Moreover, a comparison of the results obtained with these interpolation instruments (thermoelement, resistance thermometer, etc.) which measure not temperature independently but a well-defined physical property which changes continuously with the temperature, affords an excellent opportunity, *through this continuity*, for the discovery of inconsistencies in the gas thermometer measurements. The remarkable concordance of the present

[16] Sitzungsber. Akad. Wiss. Berlin **44**: 414. 1906.
[17] Ann. Physik. **22**: 19. 1907.
[18] loc. cit. p. 8.

series of thermoelectric measurements and the most extensive recent series of resistance thermometer measurements (Bureau of Standards) on the one hand with the recent gas-thermometer determinations made in this laboratory on the other, serves therefore as an efficient and independent check upon the trustworthiness of the present gas thermometer scale between 0° and 1100°.

PHYSICS.—*The expansion coefficient of graphite.* ARTHUR L. DAY and ROBERT B. SOSMAN, Geophysical Laboratory. To appear in the Journal of Industrial and Engineering Chemistry.

As a basis for the measurement of the specific volumes of silicates at high temperatures we found it necessary to know approximately the expansion coefficient of Acheson artificial graphite up to 1600°. The published data on graphite were so inconsistent and covered so small a temperature range, that we redetermined this constant over the range from 0° to 1500°; the results obtained from the material of the present paper.

The expansion was measured directly on a bar 3 mm. by 5 mm, by 700 mm. long, with a comparator which has been used in this laboratory for measuring the expansion coefficient of alloys of platinum with rhodium and iridium.[1] The comparator consists of two micrometer microscopes held at a fixed distance of 500 mm. apart by invar bars, and having mounted upon the system another invar bar by which any changes in this fixed distance amounting to 0.001 mm. or more can be detected.

Two points on the graphite bar, 500 mm. apart, were marked by flattened pieces of platinum wire bound around it, each having a fine line cut at the middle of the wire. The bar was heated by sending a heavy current through it, and a uniform temperature along its length was obtained by slightly adjusting its thickness. It was surrounded by a tube of Marquardt porcelain, and this again by a wide glass tube, each free to expand independently of the bar. The space within the tube was kept filled with carbon monoxide.

In the reducing atmosphere a thermoelement could not be used. The temperature was, therefore, found by noting the melting point of small

[1] Day and Sosman, Am. J. Sci. **26**: 425–436. 1908. **29**: 111–114. 1910. Carnegie Pub. No. 157; 27–36, 61–63. 1911.

fragments of aluminum (658°), silver (960°), copper (1083°) and the mineral diopside (1391°) lying upon the bar. Intermediate temperatures were read by means of a Holborn-Kurlbaum optical pyrometer, which thus served simply as a device for interpolating between the melting points. It was not necessary to obtain great accuracy in the temperature measurement, as the expansion is small.

Below 700° the expansion is so small that we found it necessary, in order to obtain accurate measurements of the coefficient, to use the method which we had previously employed for the platinum alloys: namely, to heat the bar in a narrow tubular resistance furnace, and read the expansion on a series of very fine lines 0.2 mm. apart, drawn with a dividing engine. These lines were drawn upon the polished ends of small plugs of silver or platinum set into the graphite at points 500 mm. apart. Up to the red heat of 700° the bar could be protected fairly well from oxidation, and contamination of the thermoelement could be prevented by enclosing it in Jena glass capillaries.

Table I contains the data. In the first two columns are given the date and the temperature at the time of the measurement. In the third column is the initial distance at 0°, between two reference lines on the silver or platinum markers on the graphite bar, in mm.; this distance was frequently changed slightly by resetting the silver or platinum markers. The fourth column contains the expansion from 0°, in mm., and the fifth, the mean linear expansion on coefficient $\frac{\Delta l}{l_0 t}$ from 0° to $t°$.

The coefficient is seen to be very small, though increasing rapidly with rising temperature. The total expansion up to 1000° is only about one-fifth of that of platinum. Two samples were used, but no systematic difference exceeding the error of measurement was observed.

The greatest uncertainty arises from changes in length of the bar after heating. In every case where the change was measurable, the bar was longer than before heating, as if this somewhat porous material had failed, after expanding, to entirely pull itself together again. The largest change noted was 0.046 mm., which is 0.009 per cent on the total length, and therefore quite negligible when the total length or volume is being considered.

Within the limits of error, the results may be expressed by the formula $10^6 \beta = 0.55 + 0.0016\, t$ in which β is the mean linear coefficient $\frac{\Delta l}{l_0 t}$ from 0°. The "true coefficient" α, or rate of expansion, $\left(\frac{1}{l_0}\frac{dl}{dt}\right)$ at any temperature t would be therefore;

$$10^6 \alpha = 0.55 + 0.0032\, t.$$

If this equation continues to hold below 0°, the true coefficient would become zero at about − 170°; in other words this

TABLE I

OBSERVED EXPANSION OF ACHESON GRAPHITE

DATE	t	l_0	EXPANSION	$\beta \times 10^6$
I. Self-heating bar				
1910				
December 2	658	499.94	0.60	1.82
	658		0.58	1.77
December 5	970	500.16	1.04	2.14
	1085		1.21	2.23
December 6	960	500.11	0.98	2.05
	1085		1.19	2.20
	1175		1.42	2.41
	1255		1.56	2.49
December 7	960	500.13	0.97	2.02
	1090		1.25	2.29
	1190		1.42	2.40
	1335		1.77	2.65
	1410		1.98	2.82
	1495		2.25	3.02
II. Platinum resistance furnace				
1911				
January 6	198	500.974	0.090	0.91
	396		0.265	1.34
January 8	202	501.020	0.075	0.74
	401		0.228	1.13
January 10	304	501.016	0.145	0.95
January 23	401	501.433	0.229	1.14
	602		0.467	1.55
January 31	403	501.279	0.274	1.35
	604		0.514	1.69
February 12	413	501.291	0.272	1.31
	616		0.506	1.64

would be the temperature of maximum density. According to Fizeau's measurements, diamond has a similar point of maximum density or zero expansion at $-42°$.

The published figures on the expansion coefficient of graphite vary widely. We do not know of any previous determinations on Acheson graphite, nor have the manufacturers a record of any. The following data have been obtained on natural graphites:

SOURCE	OBSERVER	RANGE	$\beta \times 10^6$
"Batongol" (Siberian) graphite	Fizeau*	10° to 85°	$7.45 + 0.0051t$
"Siberian" graphite	Muraoka†	Not given	3.8
"Cumberland" graphite	Dewar‡	−190° (from 17°)	24.4

* Compt. rend. **68**: 1125–1131. 1869. Pogg. Ann. **138**: 26–31. 1869. Fizeau's values are for α, the true coefficient; the mean coefficient from 0° has been calculated from the original values.

† Ann. Phys. **13**: 307–318. 1881.

‡ Proc. Roy. Soc. **70**: 237–246. 1902.

For pencil-graphite, Muraoka found the value 0.95×10^{-6} But as this is a mixture containing only 52 per cent of graphite, it is hardly comparable with data on pure materials.

The wide range of these data is striking, especially when taken in comparison with the expansion coefficients of other forms of carbon, and of carbon compounds. It will be seen from the table below that from the expansion coefficient of diamond to that of anthracite we have an increase of forty-fold.

FORM	OBSERVER	RANGE	$\beta \times 10^6$
Diamond	Fizeau*	10° to 85°	$0.60 + 0.0072t$
Arc carbons (of coke)	Muraoka	Not given	0.32
Arc carbons	Muraoka	Not given	1.5
Arc carbons	Muraoka	Not given	2.05
Arc carbons	Muraoka	Not given	3.0
Gas carbon (retorts)	Fizeau†	10° to 85°	$4.96 + 0.0055t$
Anthracite (Pennsylvania)	Fizeau†	10° to 85°	$24.02 - 0.0408t$
Coal (Charleroy)	Fizeau	10° to 85°	$26.63 + 0.0148t$
Woods, various kinds	Villari‡	43°	24 to 42

* Pogg. Ann. **128**: 583. 1866.

† Compt. rend. **68**: 1125–1131. 1869.

‡ Landolt-Börnstein-Meyerhoffer Tab. p. 202. Figures are mean linear, or one-third of cubical.

A rough parallelism is immediately evident between the temperatures of formation and the expansion coefficients of the different varieties of carbon in the two tables above. The highest coefficient is possessed by bituminous coal, which is followed closely by anthracite. The Cumberland (Borrowdale, England) graph-

ite investigated by Dewar stands next in order, and very near anthracite. This graphite has been formed in company with intrusions of igneous rock into clay-slates containing organic matter. The Batongol graphite, with a lower coefficient, occurs in veins in granite and syenite.[2] Various samples of arc light and retort carbon, all of which have probably been heated in the process of manufacture to a higher temperature than any of the natural graphites, stand next in the order of decreasing expansion. Lowest of all (excepting one sample of arc carbon made of coke) come diamond and Acheson artificial graphite. The formation temperature of diamond is unknown. The artificial graphite is made by heating anthracite, petroleum coke, etc., to a temperature above 2200°.[3]

The view has been repeatedly expressed, by Moissan,[4] Luzi,[5] and others, that none of the three forms of carbon as at present distinguished, not even diamond, can be looked upon as a substance of fixed and reproducible properties, comparable for instance to the monoclinic and rhombic forms of sulfur. In the case of graphite, there are wide variations in such physical properties as density and electrical conductivity, as well as in chemical properties such as combustibility and the formation of "graphitic acids" of widely varying composition when different kinds of graphite are treated with nitric acid and potassium chlorate.

If we look upon natural graphites as products of metamorphism from organic matter, we may imagine the complicated carbon chains and rings of the cellulose and resin compounds of bituminous and anthracite coal as persisting after the removal of the hydrogen and oxygen, giving a whole series of "graphites" whose properties change progressively as the molecules become simpler. Berthelot[6] held this view as regards amorphous carbon.

Arsem,[7] as a result of this studies on the graphitization of different forms of "amorphous" carbon, and the densities of the result-

[2] Donath, "Der Graphit," 1904.
[3] Gillett, Journ. Phys. Chem. 15: 302, 1911.
[4] Chimie Minérale, 1905, II, 222.
[5] Donath, "Der Graphit," 1904, p. 11.
[6] Ann. Chim. Phys. (4) 9: 475. 1866.
[7] Jl. Ind. and Eng. Chem. 3: 799–804. 1911.

ing products, reaches this tentative conclusion: "Graphite in the most restricted sense of the term is an allotropic form of carbon having a definite and perhaps not very complex molecular configuration. . . . . When an organic compound is decomposed, there results a mixture of substances constantly increasing in complexity until finally carbon is obtained. This carbon need not be regarded as a simple substance, but may be considered to be a mixture of many varieties of carbon each with a different number and arrangement of atoms in the molecule. . . . . In a given sample of amorphous carbon some of the molecules will be capable of easily undergoing rearrangement under the influence of heat to form graphite molecules, while others will not, and the proportion of molecules capable of such change will determine the character of the final product."

Arsem's definition is as follows: "Graphite is that allotropic form of carbon having a specific gravity of 2.25 to 2.26." This is the specific gravity of Acheson graphite, and all the graphites made by Arsem were equal to or less than this. "Those varieties of carbon which have some of the physical properties of graphite, such as color, softness, and streak, but a lower specific gravity, may perhaps be regarded as impure graphites; that is to say, mixtures of graphite with other forms of carbon."

Against the view set down in preceding paragraphs, that so-called graphite is not a simple and reproducible substance, we have the recent work of LeChatelier and Wologdine. They found that the density of Acheson and of five natural graphites after purification to remove ash and compression to drive out air, was 2.255, and conclude that this property defines graphite as a simple and reproducible substance. But the wide divergence in expansion coefficient which we have noted above seems quite beyond the range of possible experimental error, and indicates some fundamental difference between these graphites.

[1] Compt. rend. 146: 49–53. 1908.

CHEMISTRY.—*A theory of the mercury ammonia compounds.* EDWARD C. FRANKLIN, Hygienic Laboratory, U. S. Public Health and Marine Hospital Service. To appear in full in the American Chemical Journal.

The large number of products which have been prepared by the action of ammonia on mercuric oxide and mercuric salts constitute an obscure group of substances which has never received adequate theoretical treatment. In the dictionaries and handbooks of chemistry these products are for the most part described as mercuriammonium compounds, that is to say, they are assumed to be ammonium oxide, ammonium hydroxide or ammonium salts in which ammonium hydrogen is to a greater or less extent substituted by mercury, or they are complex compounds containing mercury substituted ammonium salts.

According to the theory proposed by the writer the mercury ammonia compounds, instead of being mercury substituted ammonium salts and bases, are, as a matter of fact, either (1) mercuric salts with ammonia of crystallization; (2) ammonobasic salts; (3) mixed aquobasic ammonobasic salts or (4) mixed aquo ammono bases.

An attempt will be made here to give the results arrived at by the author as applied to a few of the better known representatives of the large class of mercury ammonia compounds leaving the proofs of the inadequacy of the mercuriammonium theories together with the detailed arguments in support of the writer's theory of the nature of the mercury ammonia compounds to be found in the longer paper.

The fusible white precipitate. Over sixty years ago Kane gave this compound the formula $HgCl_2.2NH_3$, expressed in terms of modern nomenclature, and recognized it as a compound in which ammonia plays a part analogous to that of water in salts with water of crystallization. Since that time the compound has been variously formulated as mercuridiammonium chloride, $Hg\begin{matrix}NH_2\text{-}Cl \\ NH_2\text{-}Cl\end{matrix}$ that is, as ammonium chloride in which one hydrogen of each of two molecules of ammonium chloride is replaced by

the divalent mercury atom; as a compound of the infusible white precipitate and ammonium chloride as represented by the formula $NH_2HgCl.NH_4Cl$; and especially in recent years in accordance with the widely accepted Rammelsberg-Pesci theory as a double salt of dimercuriammonium chloride and ammonium chloride as represented by the formula $NHg_2Cl.3NH_4Cl$.

Now there are no known experimental facts which require the formulation of the fusible white precipitate in accordance with any of the mercuriammonium theories and since every thing known of the behavior of the fusible white precipitate indubitably places it in the class of ammonated salts, it follows that the formula given it by Kane must be accepted.

The infusible white precipitate. In accordance with the prevailing ammonium theories this compound is assumed to be either ammonium chloride in which one-half of the hydrogen is replaced by mercury as represented by the formula $Hg{:}NH_2Cl$, or as a double salt of dimercuriammonium chloride and ammonium chloride of the formula $Hg_2NCl.NH_4Cl$. The writer has shown that this compound results from the ammonolysis of normal mercuric chloride either in liquid ammonia solution or in water solution and that to it must accordingly be ascribed the formula NH_2-Hg-Cl, which represents it as an ammonobasic salt.

Millon's base. This substance has been assigned a bewildering number of formulas depending upon the view to be expressed concerning its empirical composition, for even this is uncertain, and its constitution. The prevalent views are perhaps best expressed by the formula $Hg_2NOH.nH_2O$, which represents it as dimercuriammonium hydroxide with more or less water of hydration. The writer has shown that the compound is a mixed aquo ammono base to which the formula HO-Hg-NH-Hg-OH or any one of a number of other formulas representing it as a compound, basic at the same time to both water and ammonia, may be given.

The chloride and iodide of Millon's base. When the fusible white precipitate is thoroughly washed with water, or when Millon's base is treated with a limited quantity of dilute hydrochloric acid, a compound is formed which was formerly called the chloride of Millon's base but which more recently has come to be

known as hydrated chloride of dimercuriammonium as represented by the formula $Hg_2NCl.H_2O$. The iodide of Millon's base, or Nessler's precipitate, is obtained without the presence of the elements of water and is consequently given the formula Hg_2NI, which represents it as anhydrous dimercuriammonium iodide. It is shown in the longer paper that Nessler's precipitate is an ammono basic mercuric iodide formed by the ammonolysis of normal mercuric iodide in accordance with the reversible equation

$$2HgI_2 + 4NH_3 \rightleftarrows Hg : N\text{-}Hg\text{-}I + 3NH_4I,$$

and that the chloride of Millon's base is a mixed aquo basic ammono basic salt resulting from the simultaneous hydrolysis and deammonation of the ammonobasic salt NH_2HgCl as represented by the equation

$$2NH_2\text{-}Hg\text{-}Cl + H_2O = HO\text{-}Hg\text{-}NH\text{-}Hg\text{-}Cl + NH_4Cl$$

A very large number of products are described in the literature as having been obtained by the action of aqua ammonia on mercuric salts. Many of these products are certainly not definite compounds but are basic mixtures which happened to approximate in composition the formulas assigned them. Such as are definite chemical individuals belong to one of the three classes of compounds described above, that is, they are mercuric salts with ammonia of crystallization, ammonobasic salts or aquobasic ammonobasic salts.

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

ANTHROPOLOGICAL SOCIETY OF WASHINGTON

The 461st Regular and 33d Annual Meeting of the Society was held April 30, in the New National Museum, with the president, Mr. F. W. HODGE, in the chair. The following officers were elected: President, G. R. STETSON; vice-president, FRANCIS LA FLESCHE; secretary, WILLIAM H. BABCOCK; treasurer, J. N. B. HEWITT; additional members of the board of managers, G. C. MAYNARD, FELIX NEUMANN, E. T. WILLIAMS, E. L. MORGAN, and JOHN R. SWANTON.

Several amendments to the by-laws were adopted.

TRUMAN MICHELSON, *Retiring Secretary.*

THE BOTANICAL SOCIETY OF WASHINGTON

The 81st meeting was held May 7, 1912. The following papers were read:

Further studies on the pecan "rust": F. V. RAND. A preliminary report on the fungus causing this pecan leaf disease was published in *Phytopathology*, August, 1911, under the name *Mycosphaerella convexula.* Since that time the fungus in question has been obtained from a number of other sources and several strains known to have orignated from single two-celled ascospores have been under study. In the course of one and one-half year's growth in culture, strains originally producing a majority of apparently two-celled ascospores have gradually changed until now most of the ascospores are distinctly non-septate. Furthermore a typical Gloeosporium form was developed in culture and also obtained from the host. A large number of colonies known to have originated from single ascospores or single conidia all gave cultures producing both perithecial and conidial forms, showing the two to be different phases in the life cycle of the same fungus. Inoculations on Jonathan and Yellow Newton apples gave a decay similar to bitter-rot, with production of conidia and immature perithecia on the latter. Inoculations on young pecan leaves under greenhouse conditions gave negative results but infections together with production of conidia and mature perithecia readily occurred on living leaves in damp chamber. The latter case approximates conditions in the field, since the disease has been found largely on mature leaves late in the season and under damp conditions near the ground. From the studies summarized above it would appear that the fungus is closely related to if not identical with *Glomerella rufomaculans*, and that it is not a very active parasite on the pecan.

Distribution of pigment in the seed-coat of the cowpea: ALBERT MANN. The question of the arrangement of pigments in the seed-coat of the cowpea was studied because of the bearing of certain phenomena upon questions of heredity now being studied by Prof. W. J. Spillman. Transverse sections of the seed-coat disclose three principal layers of cells, the outer one being a palisade layer with long axis vertical to the surface and with the cell cavity club-shaped and having the larger end at the lower extremity of the cell, the upper end of the cavity being often reduced to a mere thread. Second, a heavy-walled layer below this of empty cells; and third, a layer of considerably compressed cells with long axis parallel to the surface of the cowpea.

It was found that the colorations in the cowpea are the result of pigments deposited in two of these layers. In all colored cowpeas there is a basal color or practically uniform tint and invariably to be found in the lowest of the three layers, to which is therefore given the name of the basal color layer. This is a melanin compound and is of an orange-yellow tint, grading into lemon-yellow and pale buff. The changes in intensity are probably not due to a difference in the character of the pigment, but to a difference in the quantity. All other colors are obtained by superposing upon this basal color layer various pigments, and these are uniformly deposited in the palisade cells, and as a rule in the lower and larger third of the cell cavity. The colors to be found here are of practically three kinds: first, a black to blue-black, or sometimes purple tint which is an anthocyanin. Secondly a yellow or brassy-brown pigment which is some melanin compound; and third, an intense black pigment which is also a melanin compound. By various arrangements of these three superposed tints in the palisade cells, or by the absence of any pigments in these cells, the various schemes of coloration in the cowpea are obtained; the marbling, blotching, dotting, as well as the uniform colors of some cowpeas being produced by the basal color plus such superposed arrangements of color in the palisade cells as are characteristic of the different varieties.

In the case of the few cowpeas having white or colorless seed-coats, the result is obtained by the suppression of all pigments both in the basal color layer and in the palisade layer.

A wild cowpea secured from North Nigeria, Africa, is of particular interest, in that upon the same cowpea all the elements of color, as well as all the schemes of coloration are to be found. This cowpea, which is from one-seventh to one-eighth the size of the average cultivated cowpea, has a seed-coat that morphologically is identical in structure with that of cultivated cowpeas; the methods of pigment deposit are found to be also identical with those seen in the cultivated varieties.

The purpling chromogen of the Hawaiian bitter yam: H. H. BARTLETT.

Illustrations of the phytogeography of the North American Continent: JOHN W. HARSHBERGER (by invitation). The speaker displayed to the Society an album of twelve volumes of photographs and illustrations of North American vegetation collected during the preparation of his recently published work on the phytogeography of North America. The

sources of the material, and method of preparation and classification were discussed, and the general plan and scope of the work were explained in detail.

W. W. STOCKBERGER, *Corresponding Secretary.*

CHEMICAL SOCIETY OF WASHINGTON

A special meeting was held at the Cosmos Club Friday, March 1. Dr. R. B. MOORE of the Bureau of Soils gave a lecture on *Radioactivity*, illustrated by diagrams, specimens, experiments with the electroscope, and demonstration of spectra of the rare gases.

The 214th regular meeting was held at the Cosmos Club on March 14. The following papers were read:

Relations of the two sulfides of zinc: J. L. CRENSHAW, Geophysical Laboratory. Discussion by Allen.

Beet sugar manufacture: W. L. BADGER, Bureau of Standards. Illustrated with lantern slides and specimens. Discussion by Franklin.

A note was presented by DR. BLUM of Bureau of Standards on *Permanency of oxalate standards.* His experiments with coarse and fine samples showed a maximum absorption of 0.04 per cent of moisture under the most unfavorable conditions.

A special meeting was held at the Cosmos Club, March 22. DR. A. M. COMEY, director of the Eastern Laboratory of the E. I. duPont de Nemours Powder Company at Chester, Pa., delivered an illustrated lecture on *The testing of high explosives.* A smoker followed the meeting.

The 215th regular meeting was held on April 11. The following papers were read:

Relation of the chemical and physical properties of the alkali feldspars: H. E. MERWIN, Geophysical Laboratory. Discussion by Allen, who called attention to the usefulness of the petrographic microscope to the chemist.

The thermal expansion of graphite: R. B. SOSMAN, Geophysical Laboratory. Discussion: Hillebrand inquired as to the purity of the natural graphites; Wells inquired as to the effect of gases on the expansion coefficient.

Benzoic acid as an acidimetric standard: G. W. MOREY, Geophysical Laboratory. Discussion: Seidell inquired as to availability of purchasable benzoic acid for analytical use. Mr. Morey replied that high grade commercial acid should not vary more than 0.1 per cent from the pure acid, and that this variation disappears after one crystallization.

J. JOHNSTON and L. H. ADAMS exhibited crystals of calcium hydroxide and barium sulfate. Dr. Johnston explained the diffusion method for obtaining such crystals.

The first meeting of the Baltimore Branch of the Chemical Society was held in Hopkins Hall, Baltimore, on April 27. The following papers were read:

On the possibility of determining gelatin quantitatively when contained in milk and similar liquids: CHARLES GLASER.

Osmotic pressure determinations at higher temperatures (25° to 70°): PROF. H. N. MORSE. Discussed by W. Simon, W. W. Murray, E. C. Franklin, W. N. Berg.

Determination of sulfite when used as a preservative in meat. W. W. RANDALL and W. B. D. PENNIMAN.

Preliminary report on the solid acids separated from fats by means of the ammonia method: H. B. DISNEY and W. B. D. PENNIMAN. These last two were read by Dr. Randall. Discussion by C. Caspari, W. W. Murray, H. N. Morse.

A special meeting, arranged by Professor Munroe, in celebration of the centenary of the gas industry, was held at the Institute of Industrial Research on May 1. The following papers were read:

The gas centenary, its origin and meaning: PROF. CHARLES E. MUNROE, of George Washington University.

Gas appliances: WALTER R. ADDICKS, Vice-President of the Consolidated Gas Company, of New York. Discussion: In reply to a question by Sosman, Mr. Addicks outlined the possibilities of house heating by artificial gas. LeClerc inquired about the danger to life from faulty gas apparatus. Munroe brought out the point that over-enrichment may be a cause of danger by causing flames to "strike back." McBride mentioned the work being done by the Bureau of Standards on standard gas ordinances for cities.

Internal operation of the Lowe process: Illustrated. W. H. GARTLEY, Engineer of Works, United Gas Improvement Company, of Philadelphia.

Inspection of gas meters: With exhibits of apparatus. E. G. RUNYAN, Inspector of Gas and Meters for the District of Columbia. Discussion: McBride, Munroe, and Johnston brought out different phases of the specification of pressure, as well as the degree of constancy of pressure, as a municipal regulation not now in common use but of considerable importance.

Liquefied natural gas: With exhibit of apparatus. Dr. W. O. SNELLING, Chemist of the Bureau of Mines. Discussion: The relative heating values, temperatures obtainable with oxygen, and usefulness for cutting and welding, of this gas as compared with acetylene and with hydrogen were discussed by Cushman, C. O. Bond, and Crawford.

The 216th regular meeting was held on May 9 at the Cosmos Club. Dr. H. W. WILEY spoke on *The value of chemistry to the medical profession.*

ROBERT B. SOSMAN, *Acting Secretary.*

GEOLOGICAL SOCIETY OF WASHINGTON

The 252d meeting was held in the Cosmos Club, February 14, 1912, and the following papers were given:

A continually rising base level and its results: SIDNEY PAIGE.

Color photography in petrographic work. Illustrated. F. E. WRIGHT.

Undescribed glaciers of Mt. Rainier. Illustrated. F. E. MATTHES.

In his classic report on "The Glaciers of Mount Rainier," the late I. C. Russell described only six of the eleven principal ice streams of that mountain. The other five, situated on its west and southwest flanks, he did not have an opportunity to visit; and, as no one else has thus far given any description of them, they have virtually remained unknown. Last summer (1911), happily, these glaciers were mapped in the course of the topographic survey of the Mount Rainier National Park, and some data regarding them are consequently now at hand.

The interest that attaches to these glaciers arises chiefly from the fact that they are associated with the two subsidiary summits of the mountain, Peak Success and Liberty Cap. These are the two largest remnants of the rim of the main crater, and so extensive are their slopes that several large ice streams originate upon them. Indeed, of the five glaciers in question, only two, the Kautz and Tahoma glaciers, come from the summit névés of the mountain and are therefore true "primary" glaciers in the sense in which Russell used that term. The other three, the Wilson, Puyallup, and Edmunds glaciers, head in cirques situated at a level some 4000 feet lower than the summit. They are strictly speaking "secondary" or "interglaciers," to follow out Russell's classification to its logical end; but such is their size that they may easily be considered as ranking with the "primary" glaciers, and the term "secondary" scarcely seems appropriate to them. Should it be found desirable, however, to retain the distinction between primary and secondary glaciers as suggested by Russell, then it will become necessary to reclassify two of the glaciers described by him and classified by him as "primary," namely, the Carbon and Willis glaciers. Both of these ice streams originate in cirques on the sides of the Liberty Cap massif and belong to the same type as the Wilson, Payallup, and Edmunds glaciers. Of especial interest is the case of the Carbon Glacier which is perhaps the second largest ice stream on Mount Rainier. Russell sought to explain the evolution of its huge cirque as the result of the eroding action of a primary glacier cascading from the summit regions. All primary glaciers, according to him, normally tend to produce such cirques, only Carbon Glacier, owing to especially favorable circumstances, has been able to develop its cirque in advance of the other glaciers and to give it a maturely rounded form. Indeed, so far has the recession of the headwall already progressed that but little now remains of the upper névé area that formerly alimented the glacier from above. As a consequence, Russell thought, the glacier "is now destroying the very conditions on which its existence depends," and with the diminishing of the snow supply from above, will gradually decrease in size.

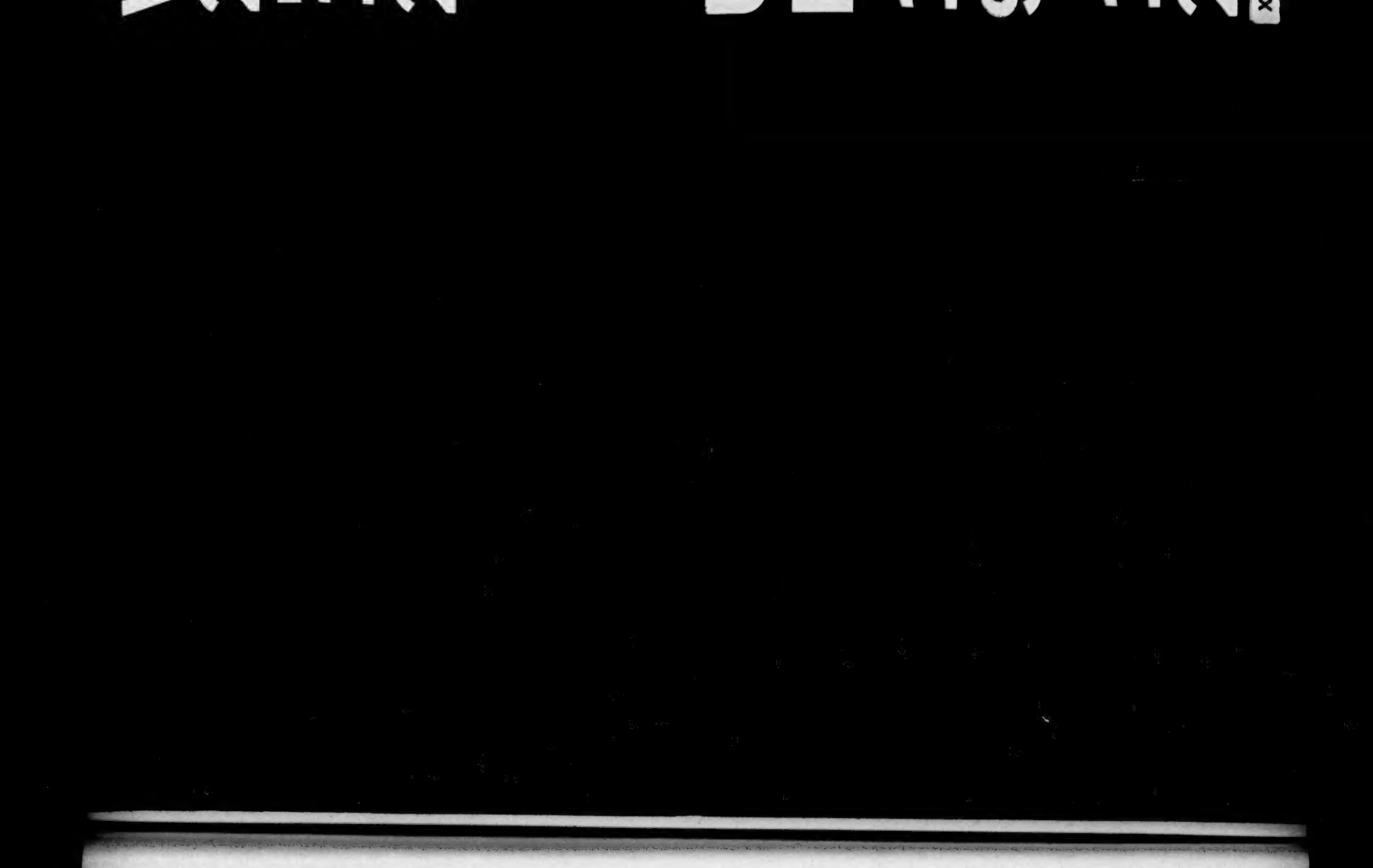
This interpretation, in the light of recent studies on cirque development, seems scarcely admissible. Cirque glaciers do not require tributary upper névés for their alimentation, but are capable of developing, and ordinarily do develop, independently from such névés. The wind is their chief alimenter, and the prime reason that cirques are capable of collecting such large quantities of snow is that they are the most capacious *windschatten* in the relief. All the cirque glaciers on Mount Rainier are to be conceived as having been initiated primarily by the accumulation of windblown snow in depressions already existing in the mountain's flanks. These depressions they have progressively enlarged into cirques through the eroding effect chiefly of their own mass movements. The enormous size and the mature character of the Carbon Glacier cirque are due, first, to the great capacity of the original depression which gave it birth, and second, to the superior eroding power of the huge ice masses it has from the beginning contained. The part played by snow descending from the summit regions has never been more than a subordinate one. The cirque, to begin with, does not head in the summit névés, but in the rocky platform surrounding Liberty Cap. What névé bodies gather on the platform are quite limited in extent, and can at no time have supplied, in the form of avalanches, more than a fraction of the total bulk of ice filling the cirque.

The Carbon Glacier, like the other glaciers mentioned, is a true cirque glacier and not a "primary" glacier in a senescent stage. Its cirque, instead of a sequential feature that is threatening to extinguish the glacier's source of alimentation on the summit, is to be regarded, rather, as the evergrowing generator of the ice mass.

The 253d meeting was held in the Cosmos Club February 28, 1912, and the following papers were presented:

Age of the Worcester (Massachusetts) phyllite: DAVID WHITE. See this Journal, **2**: 115. 1912.

The Chattanooga shale and its equivalent in the Ohio section: E. O. ULRICH.

The Chattanooga shale problems in the Southern Allegheny region: E. M. KINDLE.

RALPH W. RICHARDS, *Secretary.*